high-pressure gas is released through a discharge port 22 in the fixed scroll 23. The various compression chambers 25, 25', 29, 29' etc. arrive sequentially at discharge port 22, while new compression chambers are created by the opening and closing of the outer opening 27.

While described above as acting to compress gas, in the present application, the scroll compressor will be acting upon a mixture of helium with oil, referred to hereinafter as "gas+oil".

INTRODUCTION

A typical use for the compressed helium produced by the helium compressor of Fig. 1 is in supplying a pulse tube refrigerator 61 for the cooling of superconductive MRI magnets. A pulse tube refrigerator of known type may be supplied with high pressure pumped helium gas through an HP line 63 from the HP port 16, while a return flow of helium gas at relatively low pressure returns through an HP line 65 to LP port 18. In this context, the HP port typically provides helium gas at a pressure of around 2.4MPa (24bar), while the LP port typically receives gas at a pressure of around 0.6MPa (6bar). Present pulse tube refrigerators typically employ a rotary valve (RV) mechanism 67. A number of mutually rotating discs define valve opening and closing times, and valve orifice dimension. Such arrangements ensure correct and unchanging timing and dimension relationship between the various valves embodied in the rotary valve mechanism 67. In the present context, both the LP and HP ports would be connected to at least one valve of the rotary valve mechanism.

The HP and LP ports are typically connected to the pulse tube refrigerator with a relatively long flexible hose 63, 65. During development trials of the applicant's pulse tube refrigerator, it was noticed that some pulse tube refrigerator cold heads with rotary valve and flex lines were flooded with compressor oil over a period of time. As this occurred on four systems, it could not be considered a random event. Experiments were

performed in order to understand the mechanism of oil carry over. The present invention provides means and methods to overcome or at least alleviate the problems with the prior art compressor / pulse tube refrigerator assembly, and the present invention may be applied to any system in which a helium compressor with internal bypass relief valve has its HP and LP ports connected to a valve mechanism.

Prior to the present invention, it had been considered that the most likely cause for the presence of oil in the flex tubes was the inefficiency of the adsorber 19 connected to the HP port 16.

In an initial investigation, as shown in Fig. 1, flex line 65 to the pulse tube refrigerator (PTR) was twenty metres in length. The pressure in the HP line 63 was increased from 2.4MPa (24bar) to 2.9MPa (29bar) in steps of 0.1MPa (1 bar), being run for 4-6 hours for each step. After each step, the two metres of LP line 65 was subjected to residual gas analysis (RGA) to trace any oil in the line. The flex line under examination line was heated to approximately 200°C. In a line containing oil, very high traces of CO and CO_2 were detected, indicating the breakdown of oil within the tube under examination. The PTR was run for each trial and showed 10 K no load temperature on its second stage. The PTR was then subjected to heater loads of 40 W and 6 W at its first and second stages, respectively. However no oil could be traced under any of these conditions. The gas was always able to flow around the gas circuit 63, 67, 65 from the HP port 16 to the LP port 18.

It is known that several fault conditions may cause the rotary valve (RV) 67 to stop, while the helium compressor continues to operate. In these conditions, the helium pressure inside the HP line rises to a relatively very high value, such as 2.9 MPa (29 bar), while the helium pressure in the low pressure line falls rapidly to a relatively very low pressure, such as 0.15 MPa (1.5bar).

Further investigation was made into the effect of stopping the rotary valve 67 while the compressor was still in operation, after cooling the PTR cold head. As soon as the rotary valve stops, the helium pressure in the HP line 63 and within the connected parts of the compressor increases. The rate and magnitude of this increase depends on the stop position of the rotary valve 67. If the HP port 16 is connected to PTR in the stop position, the pressure increase in the HP line is not very high. This is due to the fact that the complete PTR volume is in line with the compressor. However, if the LP port is connected to the compressor during the rotary valve stop position, the pressure increase in the HP line is very high. As the LP port is connected to the compressor, the gas pressure in the whole LP line is reduced by the compressor to a very low value.

During the investigation rotary valve 67 was stopped in a position which increased the compressor pressure and the pressure in the HP line to 2.8-2.9MPa (28-29bar) and the compressor was run in this condition for 1-2 days. However, it was noted that the HP line showed a trace of oil in the line only after a lengthy heating time, while the LP line showed a trace oil almost instantaneously when heated. This unexpected and surprising result led to the conclusion that the oil arriving in the pulse tube refrigerator 61 and the flexible hoses 63, 65 was transferred from the compressor to the LP line first overcoming the NRV (non return valve) resistance and then went to HP line during operation via PTR cold head. This conclusion was tested and led to the present invention, which provides various methods and apparatus for preventing oil from travelling past the NRV and through the LP port.

A further investigation was performed to trace the mechanism of the oil carry-over. A pressure gauge was connected at the distal end of the two metre LP flex line 33, while the other end was connected to the LP port 18 of the compressor. The HP port 16 of the compressor was kept unattached, and therefore, blocked. The initial pressure in the LP line was 0.15MPa (1.5bar). The

According to a sixth embodiment of the present invention, as illustrated in Fig. 5, the internal bypass valve 12 is provided with its own return channel 55 to the compressor capsule 14. In this way, any gas+oil which passes through the internal bypass valve due to excess pressure in the HP line 63, for example, in the case of a stopped rotary 67 valve on an attached equipment 61, will pass directly to the compressor capsule 14, and will not be able to reach the NRV 13 or the LP line 65. Any gas+oil passing through the internal bypass valve 12 will be at a relatively high pressure, much higher than the pressure inside the LP line 65. To prevent the gas+oil from flowing through the compressor capsule 14 into the LP line 65, the return channel 55 is connected to the compressor pump, such as the scroll pump illustrated in Figs. 2A-2D at a relatively high pressure location, closer to the centre of the scrolls than the openings 27, 27' which will receive gas from the LP port 18. The return channel 55 is preferably connected to the compressor by its own manifold, deep in the core of the compressor. Since the helium gas is mixed with oil in the compressor, the fact that the return channel 61 provides gas+oil raises no problems. A disadvantage to this particular embodiment lies in that modifications are required to the compressor capsule.

While the present invention has been explained with reference to a limited number of particular embodiments, numerous alterations and variations may be made to the invention within the scope of the appended claims. Certain of the embodiments may be combined. For example, an oil trap or gas reservoir/absorber may be placed in the LP line upstream from the pressure switch. The present invention maybe usefully applied to any situation in which a helium compressor supplies compressed helium to an equipment through a system of valves. Although the invention has been particularly described with reference to pulse tube refrigerators operated though a rotary valve, it may be usefully applied to any valve controlled equipment.

CLAIMS

1. A pumped helium circuit comprising:

- a compressor with:

a high pressure port (16) and a low pressure port (18) each connected to a supplied equipment (61, 67) to respectively supply (63) compressed helium to, and receive (65) compressed helium from, the supplied equipment;

a pressure relief valve (12) operable to link the high pressure port to the low pressure port in response to a predetermined pressure differential;

a non-return valve (13) located between a low pressure side of the pressure relief valve and the low-pressure port; and

- means for preventing oil carry-over from the compressor to the supplied equipment, characterised in that said means is located (31) in the circuit between the low pressure port and the supplied equipment.

2. A pumped helium circuit according to claim 1, wherein said means comprises an oil trap.

3. A pumped helium circuit according to claim 1, wherein said means comprises an oil adsorber.

4. A pumped helium circuit according to claim 1, wherein said means comprises a gas reservoir.

5. A pumped helium circuit according to claim 1, wherein said means comprises a combined gas reservoir and oil adsorber.

6. A pumped helium circuit comprising

- a compressor with

a high pressure port (16) and a low pressure port (18) each connected to a supplied equipment (61, 67) to respectively supply compressed helium to, and receive compressed helium from, the supplied equipment;

a pressure relief valve (12) operable to link the high pressure port to the low pressure port in response to a predetermined pressure differential;

a non-return valve (13) located between a low pressure side of the pressure relief valve and the low pressure port;

and

- means for preventing oil carry-over from the compressor to the supplied equipment, characterised in that said means comprises a pressure actuated switch (51) in the circuit between the non-return valve and the supplied equipment, said switch being operable to stop operation of the compressor in response to a gas pressure at the low pressure port falling below a predetermined value, the predetermined value being less than the minimum pressure at the low pressure port during normal operation.

7. A pumped helium circuit comprising a compressor itself comprising a compressor capsule (14) with a high pressure port (16) and a low pressure port (18) each connected to a supplied equipment (61,67) to respectively supply compressed helium to, and receive compressed helium from, the supplied equipment; and a pressure relief valve (12) operable to return compressed helium from the high pressure port to the compressor capsule (14) in response to a predetermined pressure differential; characterised in that the pressure relief valve is connected (55) between the high pressure port and the compressor, directly to the compressor capsule (14).

8. A pumped helium circuit according to claim 7, wherein the return channel is connected to the compressor pump at a higher pressure location than the openings (27, 27') which receive gas from the LP port (18).

9. A method for preventing oil carry-over from a helium compressor to a supplied equipment (63, 67,61,65) comprising the steps of

supplying (63) compressed helium through a high pressure port (16) to the supplied equipment;

receiving (65) compressed helium through a low pressure port (18) from the supplied equipment;

operating a bypass relief valve (12) in response to a differential pressure exceeding a predetermined value, thereby allowing oil-laden compressed helium to flow from the high pressure port to the compressor; and

-preventing oil from the oil-laden compressed helium from travelling from the low pressure port to the supplied equipment, by providing means for preventing oil carry-over from the compressor to the supplied equipment, characterised in that said means is located **in the circuit between the low pressure port and the supplied** equipment.

10. A method for preventing oil carry-over from a helium compressor to a supplied equipment (63, 67,61,65) comprising the steps of

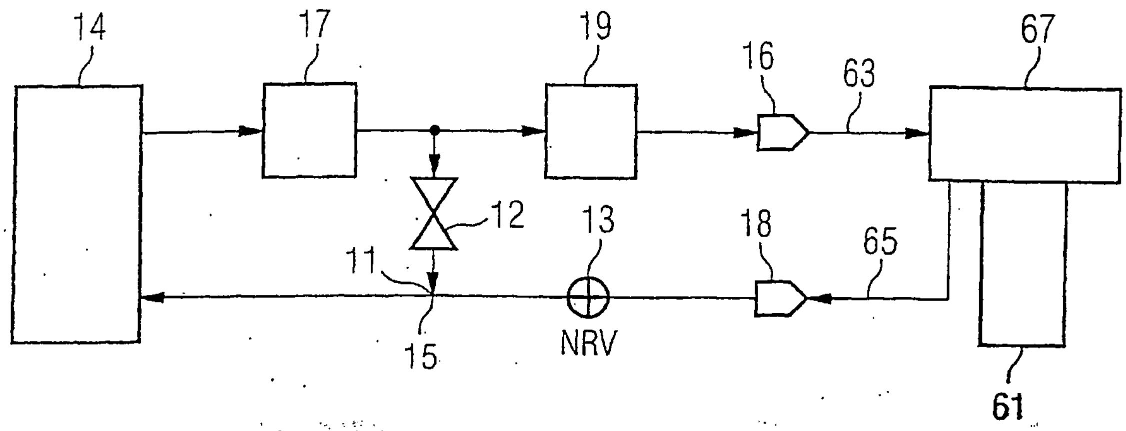
- supplying compressed helium through a high pressure port (16) to the supplied equipment;
- receiving compressed helium through a low pressure port (18) from the supplied equipment;
- operating a bypass relief valve (12) in response to a differential pressure exceeding a predetermined value, thereby allowing oil-laden compressed helium to flow from the high pressure port to the compressor; and
- preventing oil from the oil-laden compressed helium from travelling from the low pressure port to the supplied equipment, by providing a pressure actuated switch (51) in the circuit between the low pressure port (18) and the supplied equipment, said switch operating to stop operation of the compressor in response to a gas pressure at the low pressure port falling below a predetermined value, the predetermined value being less than the minimum pressure at the low pressure port during normal operation.

11. A method for preventing oil carry-over from a helium compressor to a supplied equipment (61, 67) comprising the steps of

- supplying (63) compressed helium through a high pressure port (16) to the supplied equipment;
- receiving (65) compressed helium through a low pressure port (18) from the supplied equipment;
- operating a pressure relief valve (12) in response to a differential pressure exceeding a predetermined value, thereby allowing oil-laden compressed helium to flow from the high pressure port to the compressor in response to a predetermined pressure differential; characterised in that the pressure relief valve is connected between the high pressure port and the compressor, independently of the low pressure port.

12. A method according to claim 11, wherein the return channel (61) is connected to the compressor pump at a higher pressure location than the openings (27, 27') which receive gas from the LP port (18)

FIG 1


14
17
19
16
63
67
12
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11
18
65
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NRV
61

FIG 3

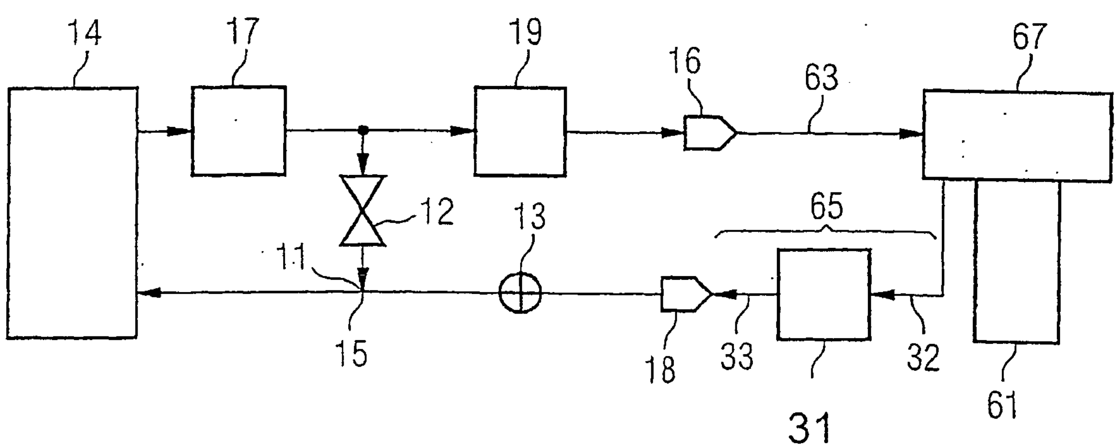
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FIG 4

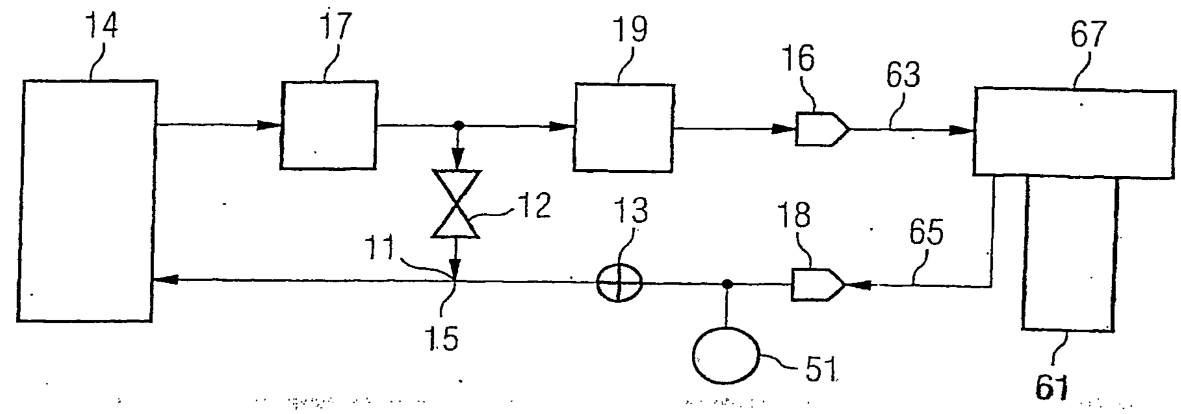
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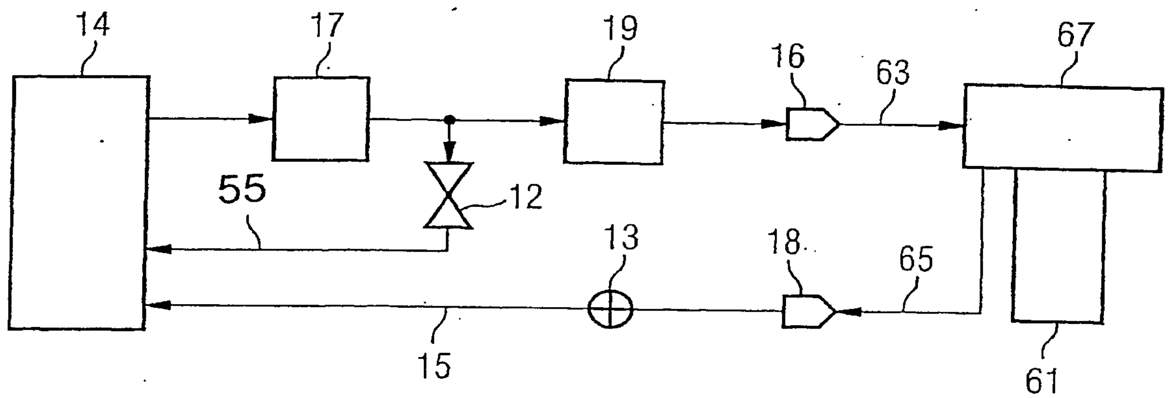
FIG 5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